A PROPOSED TERRAIN CLASSIFICATION FOR HARVESTING IN NEW ZEALAND

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ABSTRACT

A terrain classification is required to give an adequate description of the terrain conditions encountered in harvesting operations in New Zealand. Terrain classifications developed overseas have not fully met our requirements and have been modified and extended to the needs of New Zealand harvesting researchers and forest planners.

The major terrain features considered are ground condition, ground roughness, and ground slope. This follows international convention.

The measurement of ground condition relies on a cone penetrometer which relates to soil strength the number of blows to penetrate the soil to 50 cm. Ground roughness is expressed by size and frequency of the obstacles on the ground and whether they are permanent or impermanent features. Ground slope is expressed in a variety of ways (slope type, slope angle, slope length, slope aspect, and slope height) to ensure a clear expression of this important terrain characteristic. Other factors considered are slash ground cover, and standing vegetation.

Proposed data collection sheets designed for subsequent computer summary and analysis are included. A worked example shows the results of a field test.

The terrain classification requires further extensive testing by field practitioners. This will certainly result in further modification as experience is gained. The development of a relatively simple and accurate technique to measure soil moisture would add to the precision of the terrain classification.

The terrain characteristics measured are linked to a table developed by the British Forestry Commission setting out the approximate terrain limits of the more common forest extraction machinery. A task yet to be addressed is the linking of terrain difficulty to production rates. This information should be more readily available when the terrain classification is in place and an integral part of harvesting research, forest management procedures, and stand record systems.

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INTRODUCTION

In the growth cycle of a stand of trees, harvesting is one of the most costly operations. The collection of accurate, work measurement data on harvesting operations is also expensive, although vital if harvesting costs are to be kept to a minimum.

Many research organisations throughout the world and many forestry enterprises in New Zealand systematically collect information on a wide range of harvesting operations and make it available through publications. To extract the maximum benefit from this information, a number of factors must be accurately described—machinery and manpower, stand/tree characteristics, logging method, data collection procedures, and the terrain.

A terrain classification is necessary for the forest planners and managers who have to organise the various operations up to and including harvesting in the safest and most efficient way. Terrain dictates the type of machinery that can effectively and efficiently carry out a specific forest operation and will have an important effect on the cost of the operation. Therefore a terrain classification system must be accurate, repeatable, and consistent, and should be economical of manpower and effort.

The development of an international terrain classification has received considerable attention overseas for the last 15 years (Haarlaa and Asserstahl, 1972). An examination of many of these systems indicated that they could not be used directly because many of the physical features of prime importance (*e.g.*, moraines) are not important in New Zealand and some of the factors here, such as highly erodible soils, are not given sufficient emphasis (Logging Research Foundation, 1969). An attempt has therefore been made to combine the pertinent aspects of various overseas systems (Krag, 1980) together with locally developed measurement techniques to produce a terrain classification for harvesting operations in New Zealand (Chavasse *et al.,* 1979).

To ensure that this proposed terrain classification for harvesting is compatible with those developed overseas, the collected field data are summarised into the three primary categories of ground conditions, ground roughness, and ground slope.

THE PRIMARY TERRAIN FACTORS

1. Ground Conditions

Soil Types

There are six generalised soil types or conditions: parent rock, broken rock (gravels), pumice, clay, sand, and marsh. (This classification is to be supported by information from N.Z. Soil Survey Maps (Appendix 1).)

Soil Strength

Bearing capacity is measured with a cone penetrometer to assess whether an area is suitable for ground extraction machinery. Although an area has topography that lends itself to ground extraction methods, the soil may not have sufficient strength to take the weight of machinery. This is usually caused by high moisture content in the soil.

There are five broad classes for soil strength: hard, very firm, firm, soft, and very soft. These arbitrary classes are related to the number of blows of the cone penetrometer needed to penetrate to a depth of 50 cm (see Appendix 6).

2. Ground Roughness

Ground roughness is expressed by the size and frequency of obstacles that may have an effect on operational planning and management. Obstacles considered must be visible, countable, and measurable. The most common are rocks, mounds, and hollows which are permanent and logs and stumps which are impermanent (refer Appendix 3).

3. Ground Slope

Ground slope is a major physical factor affecting operations. Not only does it affect machine movement across an area but it also affects the productivity of planting crews, access for fire control, location of roads, etc. Although a slope angle has some meaning to the planner and manager, slope length and slope description must be linked with slope angle to give a clear picture of this terrain factor. Only when these features are combined can a practical assessment of suitable equipment be made. Whether a slope is positive or negative has no relevance when considering the overall slope until direction of travel has been decided.

TERRAIN ASSESSMENT PROCEDURES AND METHODS

The methods for data collection, analysis, and summary of results are presented in succeeding sections. The terrain classification has been tested in 4 areas ranging from easy (farm/forestry area, Tikitere) to steep (Whakarewarewa Forest, Moerangi) and gave satisfactory results over this range. The example used in the test is Compartment 7 Whakarewarewa Forest, a relatively difficult area. The analysis shows that the area under review is marginal tractor country because of slope and low soil strength. Observation of a tractor logging the area supports this conclusion.

Terrain Classification Area Description Sheet

The area description sheet (Appendix 1) can be completed from topographic maps, N.Z. Soil Survey maps, and local meteorological records before field measurements are undertaken.

Field Methods

The direction of preselected transects should be chosen to run at right angles to major topographical features. If this is not done major slopes will occur only as side slopes. (See topographic map, Appendix 2, for an example.)

The distance between transects and therefore the sampling intensity is decided by a subjective estimate of the "brokenness" of the terrain either by eye or from a topographic map. Where areas are flat or have a constant slope, transects should be located every 300 metres. In dissected areas transects need to be at a closer spacing so that the terrain classification can account for all changes in terrain. A maximum spacing of 250 m should be used in very dissected areas. Where a gully head is being classified, transects may be located from a reference point in a radial pattern from the floor of the gully.

The transect line is located from a reference point by compass. The first plot should be placed 10 m inside the stand edge (*i.e.,* inside a suitable buffer zone).

Subsequent plots are located at all major topographical changes —*i.e.,* where slope change is greater than or equal to 7°. On long even slopes where less than 7° changes occur, plots should be located at 100 m intervals. No slope correction factor is used for the 100 m interval.

In extremely broken terrain, plot overlap may cause double sampling of some ground roughness characteristics and slow coverage of the area to be classified. This can be overcome by adopting predetermined random grid intersects for plot locations.

The plot size is 0.04 ha to ensure that obstacles over 16 m apart can be recorded (Appendix 3). Slope correction factors need to be used to give comparable areas.

Terrain Classification Plot Sheet

(1) Slope description is the slope shape between the plot being measured and the next plot or change in topography. Slopes are described as: convex, concave, dissected, undulating, or smooth.

(2) The main slope angle (to the nearest degree) is recorded (forward and back) along the transect from plot centre to plot boundary and averaged. If the plot is properly located the difference between the two readings should be less than 7°.

(3) The slope length is measured between the centres of plots.

(4) Aspect is measured at each plot with a compass. In many instances aspect will not have changed unless the observer has crossed a ridge or side slope.

(5) The angle of side slope at right-angles to the transect (left and right) is measured through the plot centre to the plot boundary, and their aspects are measured, uphill or downhill as applicable. Frequent side slope angles greater than the slope angle on the transect line may indicate faulty transect location.

(6) The ground roughness, within the plots, is assessed by class and cause independently of slope. The class is assessed by the frequency of obstacles of a given height or depth (see Appendix 3). The number of permanent obstacles (mounds/hollows) and temporary obstacles (logging debris, stumps) are recorded as well as the number of crop trees.

(7) A locally developed drop-hammer type penetrometer made of 10 mm diameter steel rod is used. The overall length is 1.27 m with a hammer drop of 0.6 m. The drop-hammer weighs 3 kg. Three readings from each plot are taken with the penetrometer. After the litter layer is removed the average number of blows to achieve a penetration depth of 50 cm is recorded. If a depth of 50 cm has not been reached after 50 blows the penetration depth is recorded and it can be assumed that the bearing capacity of the soil is far in excess of that needed to support heavy logging machinery. (Recording the number of blows to the intermediate depths of 15 cm and 30 cm will disclose any abrupt changes in soil strength.)

(8) The size (height and length) and position (distance along transect line) of large rock outcrops or escarpments are recorded.

(9) Slash cover in ground contact is assessed on the basis of walking difficulty between sampling points: (A "deviation" is recorded if an obstacle requires a deviation of 5 m or more before the transect line can be rejoined.)

Light: Able to walk between sample points with only minor deviations from the line (0-10 deviations/100 m).

Medium: Able to walk between sample points with frequent deviations from the line (11-20 deviations/100 m).

Heavy: Able to walk between sample points with difficulty and very frequent deviations from the line (21-30 deviations/100 m).

Very heavy: Able to walk between sample points with great difficulty and constant deviations from the line (31-40+ deviations/100 m).

(10) Standing vegetation (scrub, hardwoods, etc.) is described as light, medium, heavy, or very heavy as in (9) above, with an estimate of height of the standing vegetation to the nearest metre.

(11) Soil moisture is difficult to quantify. It is assessed as dry, moist, or wet, at 15 cm, 30 cm, and 50 cm depths from a 50 cm deep soil pit dug at each major topographical change. This subjective classification can be supported by the readings from a simple soil moisture probe, graduated 1-5. A reading of 1-2.5 would indicate a dry condition, 2.6-3.5 a moist condition and 3.6-5 a wet condition. The trial probe incorporated a moving coil meter of 0.5 mA with a series resistance of 470 ohms. The main advantage of using this relatively crude measurement tool was to introduce a degree of consistency in the moisture classification procedure. A more accurate but portable measuring tool is required for this phase of the terrain classification.

(12) A rough sketch of the ground profile showing compass orientation is a good guide for a later reader to appreciate the lie of the land.

METHODS FOR ANALYSIS OF TERRAIN DATA

Terrain Classification Summary Sheet (See Appendix 5 example)

After the field assessment has been completed, the data from the plot sheets are summarised as described below.

1. Ground Conditions

The major soil type found in the assessment area is recorded.

Soil Strength

The number of blows taken to reach penetration depths of 15 cm, 30 cm, and 50 cm at each sample point along the transect is averaged for the area and recorded. Below 15 blows the planner should consider low ground pressure machinery or even cable systems. Where more than 15 blows are required, it is assumed (at this stage) that ground extraction machinery can be used without serious traction problems. If, after 50 blows, a penetration depth of 50 cm has not been achieved, the depth penetrated is noted instead. The range of the number of blows or penetration depths is also recorded. (See Appendix 6 for strength classes.) As more soil types are sampled it should be possible to set guidelines for individual soil types. Soil damage through compaction has not been considered in this exercise.

From the samples taken the percentage of the area containing low bearing strength soils can be found. If the percentage is small the planner can often avoid these areas or treat them with special care. Where these areas predominate the planner is forewarned of the need for alternative extraction machinery. Bearing capacity, as measured by the penetrometer, will be a prime measurement for the ground condition classification. However, penetrometer readings must be interpreted with soil moisture content to ensure correct ground condition classification. For example, the clay soils of Maramarua Forest after a dry spell would show suitability for ground-extraction. This would not be a correct interpretation on an annual basis, particularly in the wet season. This caution would apply to all measurements where a high clay content is present.

Soil Moisture

The percentage occurrence of each moisture class (dry, moist, or wet) is calculated at each depth (15 cm, 30 cm, 50 cm) to show the dominant classification at each level.

2. Ground Roughness Class

The percentage occurrence of each class recorded throughout the total length of the transects is calculated. Often more than one cause of roughness will be recorded at each assessment point so these may not add up to 100%.

Slash Cover and Standing Vegetation

The following categories are recognised for these features: light, medium, heavy, very heavy. The most common category is recorded for these two features.

3. SLOPE

Slope Type

The percentage of each slope type present is calculated to give a comparison of the range and extent of each type of slope present. By using percentages the number of sample plots or sampling intensity does not affect the comparison of one area with another.

Slope Angle

The mean absolute slope gives an indication of the average steepness of an area. For this calculation signs are ignored (—10° and +20° mean absolute slope = 15°).

The mean change of slope is calculated by finding the mean of absolute slope changes recorded between successive sample plots. Thus a change from +23° to —22° equals 45°. If the next sample point had a slope of —19° the change from —22° would be 3° and the average of 45° and 3° will be 24°.

The range of slopes is taken from the most extreme positive to the most extreme negative slope. Where the whole slope is in one direction the smallest and largest slope angles are used as the range.

Slope Length

The average slope length and the range of lengths are calculated.

Side Slope

The average side slope is calculated ignoring the sign.

Slope Aspect

This is presented as a directional diagram. The length of each vane is proportional to the percentage occurrence of corresponding aspect at the assessment points along the transects.

APPLICATION AND FUTURE DEVELOPMENT

It is assumed that the terrain classification will be recorded and remain as an integral part of the stand/forest records and therefore will be available to the planner at harvest planning time.

In order to comply with international convention a table entitled the "Classification of Terrain Chart" (Appendix 6) has been constructed (Logging Research Foundation, 1969). This lists the 5 classes of each factor—ground condition, ground roughness, and slope. Terrain classification should follow this ranking. However, it will be a better description if it is supported by the additional information contained in the Area Summary Sheet.

Appendix 7 sets out the approximate limits of extraction machinery with reference to terrain conditions. These limits were developed for conditions in Great Britain (Sutton, 1980) but appear to have revelance to New Zealand conditions. Further testing and experience with the developed terrain classification will inevitably lead to modifications to suit our needs.

A further phase of development will be the construction of graphs and tables showing the reductions in productivity for a range of machines over a range of terrain difficulty.

AN EXAMPLE OF THE USE OF THE TERRAIN CLASSIFICATION

Classification of Compartment 7 Whakarewarewa Forest

Referring to the Area Summary Sheet (Appendix 5) ground conditions in relation to the penetrometer results show 13.5 blows to 50 cm. The mean ground roughness class is shown as 3.5, and the mean slope 17°.

The Classification of Terrain Chart (Appendix 6) shows that Cpt. 7 falls into the Class 5 classification, *i.e.,* very poor in regard to ground condition. Ground roughness class is 3.5 which is between uneven and rough. A mean slope reading of 17° puts Cpt. 7 into the moderate slope category. Following international convention, the part of Cpt. 7 sampled would be classed as 5:3.5:3. Appendix 7 shows that Cpt. 7 with this classification would fall in the crawler tractor category in relation to ground roughness and slope and would be considered marginal for ground extraction because of class 5 ground condition. Recent observation of the logging of the area with a crawler tractor supports this view.

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APPENDIX 1

Terrain Classification Area Description Sheet

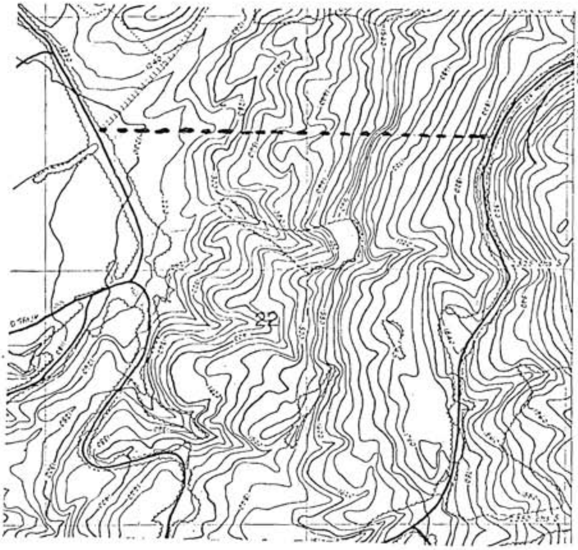
Location ....
Altitude ....
Frosts per Annum .... Average Annual Snowfall (m) ....
Average Annual Rainfall (mm) ....
Months with Highest Rainfall ....
Number of Rain Days/Annum ....
Rainfall Month Preceding (mm) ....
Rainfall Preceding 24 hours (mm) ....
Soil Description from N.Z. Soil Survey Maps (NZMS 1) ....
Soil Type Code* ....

Date of Survey .... Recorder ....
Crop Species ....
Total Stems/ha ....
Number of Plots .... Plot Radius ....

*1. Parent rock
2. Broken rock (gravels)
3. Pumice
4. Clay
5. Sand
6. Marsh

APPENDIX 2

Transect Location



APPENDIX 3

Ground Roughness Classes

Obstacle Height/Depth	*Class 1 Even*	*Class 2 Slightly uneven*	*Class 3 Uneven*	*Class 4 Rough*	*Class 5 Very rough*
Up to 20 cm	Infrequent/ Moderate	Moderate/ Frequent	Frequent	Frequent	Frequent
Up to 40 cm	Isolated	Moderate	Moderate	Frequent	Frequent
Up to 60 cm	None	Isolated	Infrequent	Moderate	Frequent
Over 60 cm	None	None	Isolated	Isolated	Frequent

Definition of Frequency

	Spacing	*Obstacles/ha*
Frequent	$<$1.6 m	$>$4000
Moderately Frequent	1.6-5.0 m	400-4000
Infrequent	5.0-16.0 m	40-400
Isolated	$>$16.0 m	$<$40

Type of obstacles

Permanent:	Impermanent:
Rocks	Logs
Mounds*	Stumps
Hollows*	Trees

*Not recorded where diameter is more than 6 times the depth

APPENDIX 4

Terrain Classification Plot Sheet

Date .... Recorder .... Area Name ....
New Transect (Y/N) .... Plot Number ....
Slope Description* .... Slope Length (m) ....
Main Slope (degrees ±) .... Side Slope (degrees ±) Left ....
Aspect Bearing (degrees) .... Right ....
Aspect Slope (degrees) ....
Deviations/100 m Slash .... Standing Scrub .... Height (m) ....

Penetrometer	15 cm	30 cm	50 cm
Reading 1	....	....	....
2	....	....	....
3	....	....	....
Soil Moisture			

Ground Roughness (tally)	Obstacle height class (cm) 0-20	20-40	40-60	>60
Permanent Rocks				
Permanent Mounds				
Permanent Hollows				

Rocks ....
Permanent Mounds ....
Hollows ....

Ground Roughness (tally)	Obstacle height class (cm) 0-20	20-40	40-60	>60

Logs ....
Impermanent Stumps ....
Trees ....

Other (specify)

Outcrops (m) Distance .... Size .... Height ....
....

Ground Profile about Plot

Comments
Scrub species
Other

*Slope description 1 = Convex
2 = Concave
3 = Dissected
4 = Undulating
5 = Smooth

APPENDIX 5

Terrain Classification Summary Sheet
(Example not complete)

Location (Name) Cpt. 7
Area (ha) 14
Altitude (m) 300
*Soil type code** Pumice
Number of rain days per annum
Months with highest rainfall

Grid ref
(N.Z.M.S. 1)
Average annual rainfall (mm)
Average annual snowfall (m)
Number of frosts per annum

Date of Survey 25/11/81
Plot area 0.04
Tree Crop (stems/ha)

Number of Lines/Plots 21
Rainfall month preceding (mm)
Rainfall 24 hours preceding (mm)

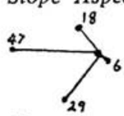
Soil Description from N.Z. Soil Survey Maps (N.Z.M.S. 1)

Area Summary Sheet

Slope Type (%)†
Convex 12
Concave 24
Dissected 0
Undulating 41
Smooth 24
Slope Length (m)
Average length
Range of lengths
Side Slope (°)

Ground roughness (%)†
Rocks 0
Mounds 6
Hollows 41
Logs 18
Stumps 29
Trees‡ 100
Other 0

Slope Angle (°)
Mean absolute slope 17
Mean change of slope 14
Range of slopes +30 to —23
No. of positive slopes 15
No. of negative slopes 2
*Slope Aspect (%)**



N.W. 18
W. 47
S.E. 6
S.W. 29

Ground roughness class (%)†
Class 1 0
Class 2 29
Class 3 41
Class 4 0
Class 5 29

Deviations Slash 2.44/100 Light
Deviations Standing Scrub 2.57/100 Light

Penetrometer *Moisture Classification*
Ave blows to 15 cm 3.4 Predominant condition at 15 cm Dry (76%)
Ave blows to 30 cm 7.1 Predominant condition at 30 cm Dry-moist (52%)
Ave blows to 50 cm 13.5 Predominant condition at 50 cm Moist-wet (64%)
Range of blows to 50 cm 3-28

Comments

Overall Classification Codes: *Ground Conditions* 5
Ground roughness 3.5
Slope 3(4)

International Convention Prediction Crawler tractor downhill
Survey Time as Stand Rotation Age Clearfell
Other Because of ground conditions; and slope being near upper operating limits of crawler tractor; cable cranes are recommended

*Classes: Parent rock, broken rock (gravels), pumice, clays, sand, marsh.
†% may not add to 100 because of multiple classification
‡Commercial species stocking

APPENDIX 6
Classification of Terrain Chart

Class 1	Class 2	Class 3	Class 4	Class 5
GROUND CONDITIONS (PENETROMETER)				
Very good	Good	Average	Poor	Very poor
Consolidated pumice Hard 50*/50 cm	Broken rock (gravels) Very firm 40-50/50 cm	Soft mineral soils Firm 30-40/50 cm	Wet clays Soft 15-30/50 cm	Semi-marsh Very soft 0-15/50 cm
GROUND ROUGHNESS				
Very even	Slightly uneven	Uneven	Rough	Very rough
Infrequent obstacles 20 cm in height/depth; 40-400/ha. Isolated obstacles up to 40 cm	Moderately frequent obstacles up to 20 cm height/depth; 400-4000/ha. Moderate number up to 40 cm; 400-4000 ha	Moderately frequent obstacles up to 40 cm in height/depth; 400-4000/ha. Isolated obstacles >60 cm	Moderately frequent obstacles up to 60 cm in height/depth. Frequent obstacles up to 40 cm. 400-4000/ha	Frequent obstacles up to 60 cm in height and depth. Greater than 4000/ha of obstacles 20-60 cm in height/depth at <1.6 m spacing
MEAN ABSOLUTE SLOPE				
Level	Gentle	Moderate	Steep	Very steep
0-10% 0-6°	11-20% 7-11°	21-33% 12-18°	34-50% 19-27°	+51% +28°

*50+ blows to penetrate to 50 cm

APPENDIX 7

Approximate Terrain Limits of Extraction Machinery

Machine type	*Worst terrain class on which machine can be expected to operate* — *Ground conditions*	*Ground roughness*	*Slope*	*Remarks*
Agricultural tractors 2-wheel drive:				
Extraction—uphill	3	3	2	Uphill extraction may
—downhill	4	3	3	require reduced load
Agricultural tractors 4-wheel drive:				
—uphill	3	4	3	Uphill extraction may
—downhill	4	4	4	require reduced load
Forwarders frame-steered:				
—uphill	3	4	3	Uphill extraction may require reduced load
—downhill	4	4	4	Band-tracks essential in worst conditions
Skidders frame-steered:				
—uphill	3	4	3	Band-tracks essential
or	4	4	2	in worst conditions
—downhill	4	4	4	
Crawler tractors:				
—uphill	4	4	3	
—downhill	4	4	4	
Cablecranes	5	5	5	

Notes: 1. Each class covers a range, and it should never be assumed that a machine will operate at the extreme limit of the class. For example, frame-steered skidders extracting downhill will probably cope fairly well with poor ground conditions (4) and rough ground (4) if the slope is in the lower portion of class 4—say 33 to 38%—but might find it difficult at the upper limit, 45-50%. Classes in the above table are borderline; the table is a general guide only.

2. Most tractors can run on "very poor" ground conditions (Class 5) if a carpet of brush can be provided and if slopes are no greater than the lower end of class 3. Flotation tyres or band-tracks are desirable in addition to brush. Band-tracks are essential on soft or steep ground.